A Look-up-table Approach to Inverting Remotely Sensed Ocean Color Data

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LONG-TERM GOAL

The overall goal of this work is to develop and evaluate a new spectrum-matching technique for rapidly inverting remotely sensed hyperspectral reflectances to recover environmental information such as water-column optical properties, bottom bathymetry, and bottom classification.

OBJECTIVES

The work for the Look-Up-Table (LUT) approach to inverting remote sensing ended on this grant at the beginning of the year. It continues under a new grant, N000140610370, and again led by PI C. Mobley, N0001406C0177. This grant (N000140110201) was expanded during 2006 to include MultiSpectral Imaging/HyperSpectral Imaging (MSI/HSI) overflights for the Naval Research Laboratory-Stennis Space Center (NRL-SSC) during April 2006. It was also expanded to allow for the purchase of capital equipment to refine the HSI sensor calibration to provide a more robust data stream for the LUT inversion approach.

APPROACH

Expansion 1. Our programs on automated feature extraction from remotely sensed imagery in the coastal zone has been focused on off-shore coastal waters or tidally-driven estuaries with salinities approaching those of off-shore waters. However, there are coastal regions where fresh water inputs into the near-shore environment are significant, dramatically altering the expected IOPs and bottom types within these environments. This will significantly alter the expected error budgets for any bathymetry, bottom classification, target identification, or IOP algorithms designed for saline marine conditions. In addition, the area of operations for Naval Special Boat Teams does not stop at the shoreline; rather the SBTs move inland along river routes to target areas. SBTs have similar bathymetric and shoreline mapping requirements as those operators moving onto traditional beach zone environments. We currently do not have HyperSpectral Imagery (HSI) data for these inshore, fresh water, environments with which to develop, test, and validate our LUT methodology. This expansion proposal is to collect the HSI data stream to continue the development of LUT for ship to shore operations.

This 2006 expansion is to build upon other HSI and LUT efforts by FERI, and the Naval Research Laboratory at Stennis Space Center (NRL-SSC). This collaboration offers the ability to collect the HSI

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and provide the requisite ground control data at a much less expensive cost point than were we to focus on this collection as a stand alone effort. This collaborative effort will be in the region of the Pearl River, with FERI supplying flight support services, and ortho-rectified airborne HSI and high resolution MultiSpectral Imagery (MSI). NRL-SSC (PI-A. Weidemann) will be responsible for ground support operations, as well as ground control and validation data streams.

Figure 1. The region of the Pearl River to be covered by 1 m HSI and 0.15 m MSI between March 31 and April 7, 2006.

<u>Expansion 2.</u> The overall goal of this LUT project is to develop near-real time processing and algorithms to characterize Very Shallow Water (VSW) BattleSpace Environments (BSE), as well as target detection capabilities for Mine Counter Measures (MCM) using HyperSpectral Imaging (HSI) techniques. This LUT project is focused on the processing and mathematics associated with the development of new quantitative methods to identify targets, classify unknown materials, determine bathymetry, and assess the vertical structure of inherent optical properties in the water. (The HSI data used in this project is, or has been, collected via other funded efforts.) The ability to accomplish these tasks with high confidence and low false-alarm rates is directly dependent on the data quality and error chain associated with the data's collection and processing. This expansion proposal is to develop the capabilities to reduce the uncertainties associated with the beginning steps of the data processing chain.

In order to develop confidence levels and target error rates in our techniques, it is necessary to understand the basic premise of our approach. The LUT methodology is built upon radiative transfer theory and models. The target signal is modeled based on previously measured (in the case of defined targets such as sand or rock) or modeled (in the case of vertically structured absorption and scattering) and compared against the aircraft or satellite measured HSI data, after it has been calibrated and adjusted for illumination and atmospheric effects. The target radiances are traditionally very low compared to the total sensor measured radiance, as the atmospheric signal is frequently greater than 90% of the total measured upwelling radiance. Therefore, any errors and noise associated with the originating HSI sensor data has a magnified effect on the comparison of the atmospherically-adjusted HSI spectra and the modeled target reflectance spectra.

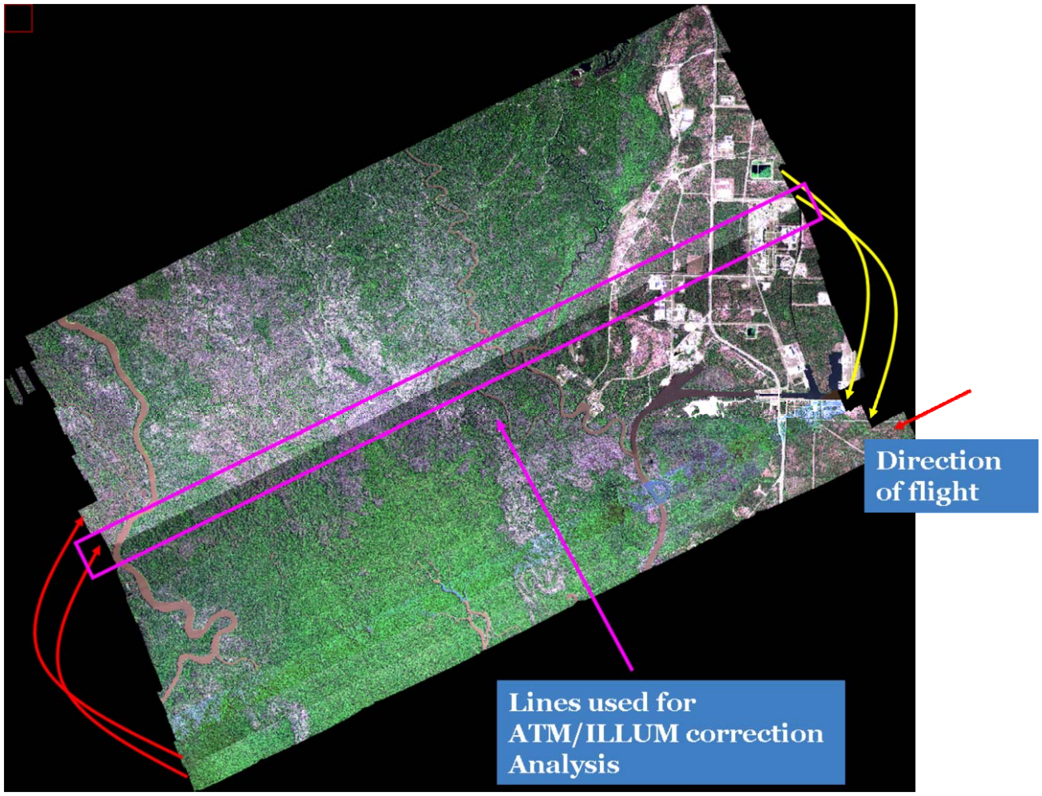

Figure 2. The region of the Pearl River covered by 1 m HSI and 0.15 m MSI on April 4, 2006. The lines were flow in the afternoon in an ascending race track starting at the southeast corner. The illumination changes are caused by the change in solar elevation during the flight window. The two center lines in the magenta box in the center of the image were the 2nd and 19th flight lines collected, representing beginning and ending of the flight window. These two lines are shown together in Figure 4 after atmospheric and illumination correction.

There are three broad sources of systematic and unsystematic errors in this methodology. The first is in the error and noise associated with the modeling of the target signals. The second is with the error and noise associated with the calibration of the sensor. The third source is found within the modeling and correction of the illumination and atmospheric conditions. This expansion is focused on reducing the uncertainties associated with the sensor calibration by explicitly measuring the spectral response function of our SAMSON HSI system.

Our current calibration takes into consideration the spectral response function implicitly through the radiometric calibration of multiple color filtered measurements of a diffuse light source (Kohler et al., 2004). While our approach has been reasonably successful at calibrating this type of system, this LUT project calls for the development of the techniques, as well as the explicit calculation of error rates and confidence levels. In order to better achieve these goals, we sought to purchase an Optronic OL 750-M-DS double monochromator. This expansion will allow us to design and conduct more detailed spectral calibrations of our HSI sensor, which in turn will create a more robust HSI data stream reducing the systematic errors in our current processing chain, as well as more completely describe the noise component of the measured spectra. The net result of this expansion will yield better LUT target and classification retrievals, and higher, more definable, confidence in those retrievals.

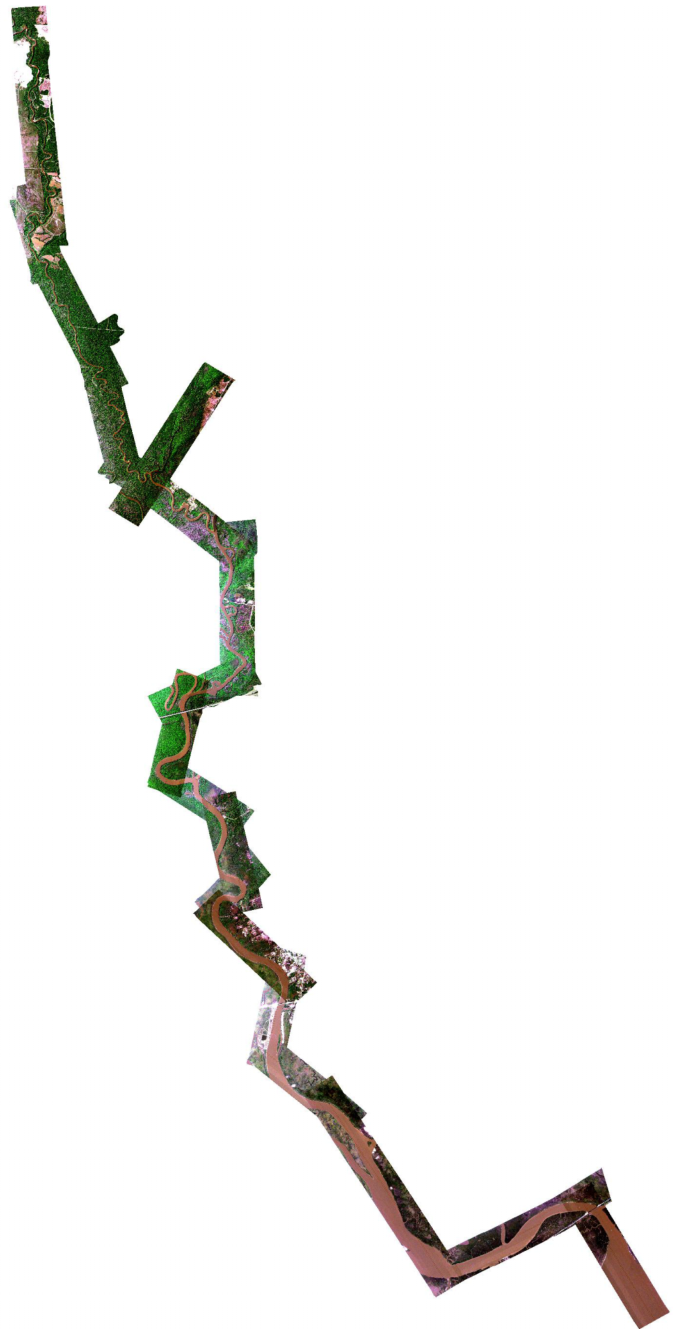

Figure 3. Simulated "Man-Down" mission capturing the entire Pearl River from the mouth of the river to the area north of NRL-SSC. The goal was to demonstrate rapid response in airborne HSI collection.

WORK COMPLETED

Expansion 1. The NRL-SSC Pearl River mission was conducted during the period March 31 – April 6, 2006. We were able to accomplish both the proposed primary mission (Figure 2) on April 4, 2006, as well as a spontaneous secondary mission defined by A. Weidemann to simulate a "man-down" scenario (Figure 3). The primary mission data have been atmospherically-corrected using a technique devised for missions without ground support (Figure 4), which rendered a full scene mosaic of HSI data (Figure 5).

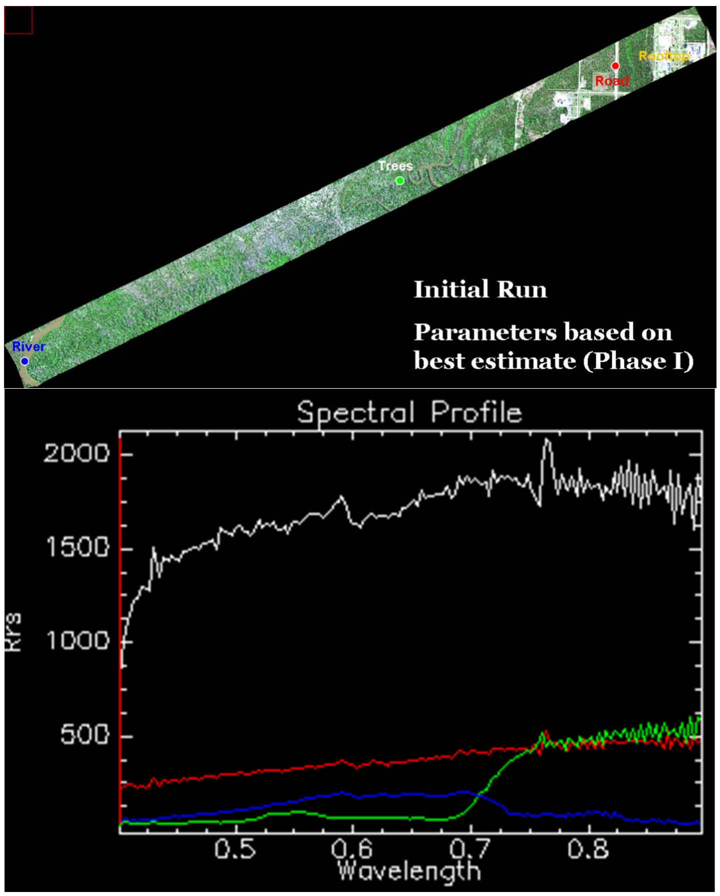

Figure 4. The flight data represented by the strip at the top of this figure is the combined two center flight lines in the magenta box seen in Figure 2 after atmospheric and illumination correction. The spectra in the bottom of the figure are the points in the top labeled as River (blue point/line), Trees (green point/line), Road (red point/line), and Roof Top (yellow point/white line). Rrs is in units 1/sr * 1000.

Expansion 2. The double monochromator was delivered in July 2006 (Figure 6) and used to calibrate our 1 m integrating sphere (Figure 6). This calibrated sphere was used to post-mission calibrate our SAMSON HSI sensor from the March and April flight operations. We are working through the differences between the pre-mission calibration data collected at NRL-DC and the post-mission calibration data collected at FERI (Figure 6)

RESULTS

Expansion 1. Figures 4 and 5 demonstrate one of multiple techniques we have developed to accomplish the atmospheric and illumination correction in near-real time. The method shown in these figures was based on a collection of best estimates of various atmospheric parameters, i.e. water vapor, ozone, aerosol type, during the flight, which allows us to rapidly generate spectral reflectance in a few hours from the end of collection. The man-down mission in Figure 3 demonstrated the ability of our flight planning, deployment, and processing systems to rapidly respond to a simulated high priority mission.

Figure 5. Environmentally corrected HSI image from data seen in Figure 3.

Expansion 2. The spectral radiometric calibration of FERI's Labsphere 1 m integrating sphere shows some differences in the calibrated spectral radiant intensity at the 10 lamp illumination setting. This could be caused by a number of factors, including the difference in aging of the bulbs and sphere coating between the NRL's and FERI's spheres. In addition, we expect that there should be some significant differences in the blue because of the use of a single monochromator (versus a double monochromator) in the calibration of the NRL sphere.

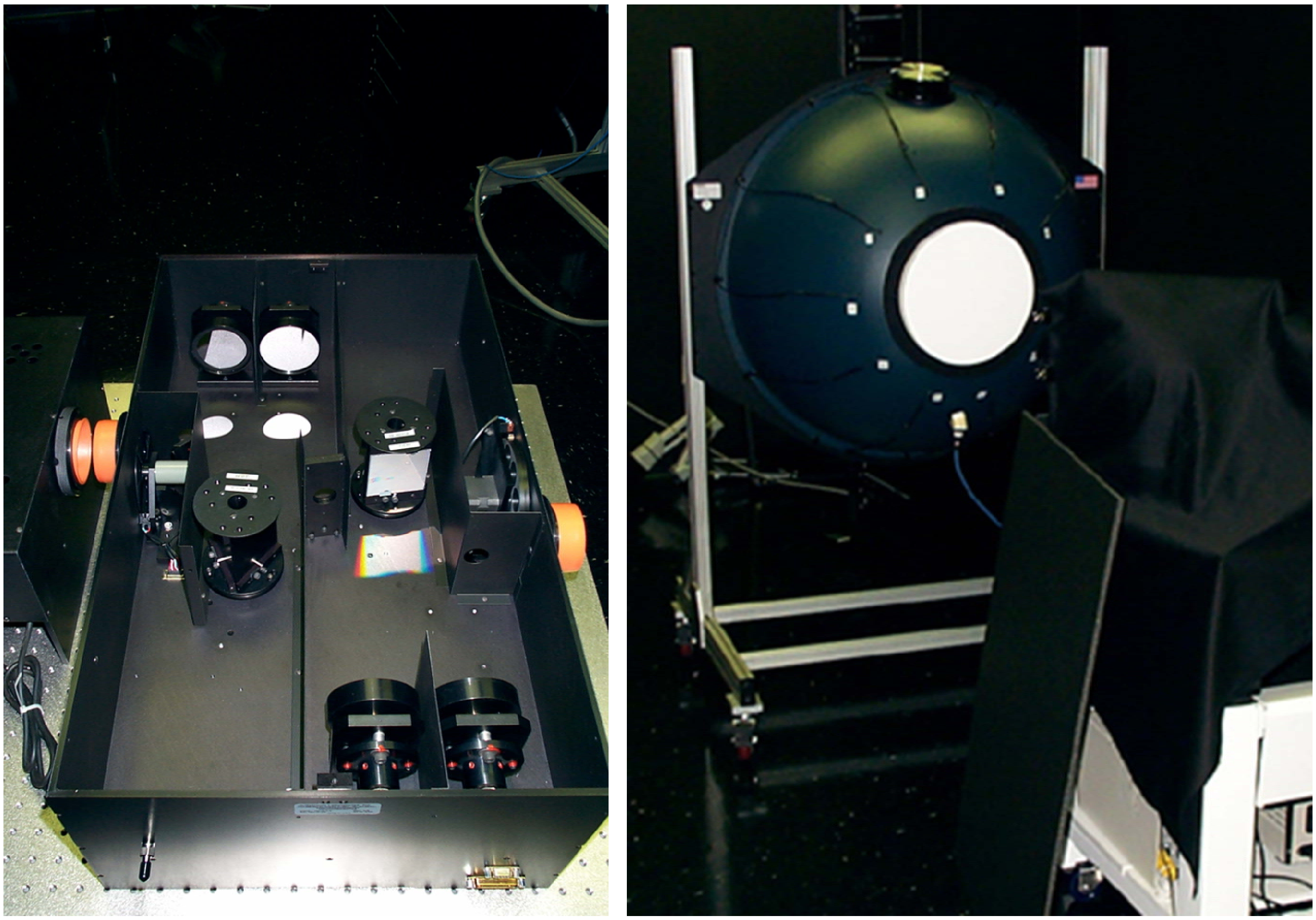

Figure 6. The Optronic's 750 DM/S Double Monochromator (left) and its use in calibrating FERI's Lapsphere 1 m integrating sphere (right). The double monochromator is covered in a black drop cloth when placed in front of the sphere.

IMPACT/APPLICATION

The problem of extracting environmental information from remotely sensed ocean color spectra is fundamental to a wide range of basic and applied science problems. Extraction of bathymetry and bottom classification is especially valuable for planning military operations in denied access areas. No single inversion technique can be expected to be superior in all situations; therefore all techniques must be evaluated. In addition to investigating a new type of inversion, part of our work is to evaluate when the LUT technique is superior to other techniques, and when it is not. This work thus adds to the existing suite of remote sensing analysis techniques. These expansion missions focused specifically on the ability to reduce the errors in the LUT techniques through better sensor calibration, and on the collection of operational areas of interest for Naval Special Boat Teams.

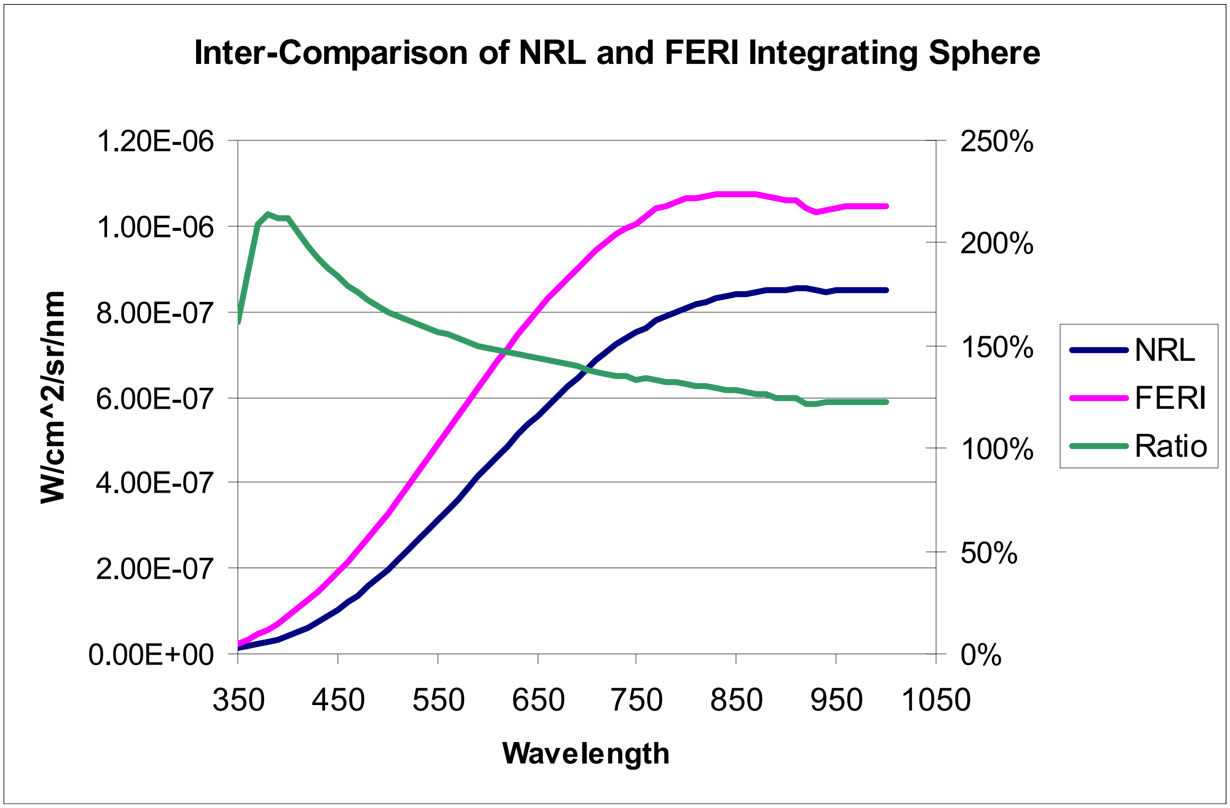

Figure 7. Inter-comparison of NRL and FERI Integrating Spheres. The ratio is FERI's Sphere at 10 Lamps: NRL's Sphere at 10 Lamps. FERI sphere is brighter, and "bluer" than the NRL sphere. Some of this may be due to the age of the lamps and sphere coating at NRL, as well as the use of a single monochromator in the calibration of the NRL sphere.

RELATED PROJECTS

This work is being conducted in conjunction Curt Mobley, N0001404C0218 and N0001406C0177, and additional ONR programs funded to the PI, N000140410297 and N000140610370).

PUBLICATIONS

Mobley, C. D., L. K. Sundman, C. O. Davis, T. V. Downes, R. A. Leathers, M. J. Montes, J. H. Bowles, W. P. Bissett, D. D. R. Kohler, R. P. Reid, E. M. Louchard, and A. Gleason, 2005. Interpretation of hyperspectral remote-sensing imagery via spectrum matching and look-up tables. *Applied Optics* **44**(17), 3576-3592. [published, refereed]

Mobley, C.D., Stramski, D., Bissett, W.P. and Boss, E., 2004. Optical modeling of ocean waters: Is the Case 1 - Case 2 classification still useful? Oceanography, 17(2): 60-67, [published, refereed].